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1. Your reference — W071549PGB

09JUL03 E821160-3 D00355
P01/7700 0.00-0316002.5

2. Patent application number *(The Patent Office will fill in this part)* — 0316002.5

09 JUL 2003

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

Aston University
Aston Triangle
Birmingham
B4 7ET

Patents ADP number *(if you know it)* — 690162300l

If the applicant is a corporate body, give the country/state of its incorporation — England

4. Title of the invention — SENSING SYSTEM AND METHOD

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

Marks & Clerk
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Suffolk Street Queensway
Birmingham
B1 1TT
England

Patents ADP number *(if you know it)* — 18002

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

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Continuation sheets of this form	
Description	13
Claim *(s)*	
Abstract	
Drawing *(s)*	4 + 4

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Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
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11. I/We request the grant of a patent on the basis of this application.

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Date 8/7/03

12. Name and daytime telephone number of person to contact in the United Kingdom — David I Ward 0121 643 5881

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SENSING SYSTEM AND METHOD

The present invention relates to a sensing system, particularly a system capable of sensing and interpreting dynamic forces.

There are a range of force sensing systems that can be employed to measure contact forces in a tactile process. There are point force sensors that include single axis or multi-axis force sensing devices that can detect the force acting through a known point. By deploying point force sensing elements to the corners of a rigid flat plate, it is possible to produce a force plate that can be used to evaluate the magnitude and position of the centroid of a contacting force. Force array surfaces can determine the contact impression of new objects through the determination of forces applied to a matrix of discrete point force sensing elements. The positional resolution of such arrays depends directly on the separation of the individual sensing elements. Both force plates and arrays can be manufactured to determine shear force in addition to normal force components to a surface. These systems can be employed to detect both static and transient forces, and arrays can be employed to evaluate distributive contact conditions. Array sensors and multi-axis sensors are of complex construction with many electrical connections. The limit to the spatial resolution of array sensors is based on the minimum scale of micro-fabrication of the surface embodying the sensing elements and the many conductive tracks and connectors to transmit signals to the outside world.

It is an object of the present invention to provide an improved sensing system which obviates or mitigates at least one of the disadvantages of the prior art sensing systems.

According to the present invention there is provided a sensing system comprising:-

a deformable load bearing surface ,

a plurality of mutually spaced sensors, said sensors being coupled through the deformation response of the surface to an applied load whereby to receive local sensory data from said surface,

a processor operatively coupled to said sensors and arranged to receive streams of sensory data from the sensors and to transform said sensory data into information data relating to a load applied to the surface, and

an output for outputting the information data,

wherein the processor is arranged to process the sensory data received by all the sensors collectively and wherein there is a non-linear relationship between the streams of sensory data from which the information data is derived.

It will be understood that by collective processing of the sensory data is meant that the sensory data from each sensor is combined with the sensory data from each of the other sensors and the information data is derived from the combined sensory dataset. In other words, the information data is not derived from a simple sum of the individually processed sensory data from each sensor. As each sensor output is affected by the applied load anywhere over the surface, the positioning of the sensors is only determined to optimise the discrimination between

variations in the applied load. Thus, the importance of the deformation in the sense of the surface continuum is that there is coupling between sensor outputs and that the effects of loading anywhere on the surface are transmitted to all individual sensors by the response of the surface. This is in contrast with array sensors where sensing elements respond only to loads applied at the same points as the sensing elements.

The number of sensors varies according to the nature of the information to be determined. However, the non-linearity allows complex information to be determined using relatively fewer sensors than would be required in a standard sensor array. Typically, the system has 3 to 10 sensors and most preferably 4 to 6 sensors. It will be understood that although fewer sensors are required for the functioning of the system, it may be desirable to provide more sensors than is strictly necessary (redundancy) to increase the robustness of the system and to allow for failure of some sensors, whereupon the remainder can be used to infer the information data corresponding to the applied load.

Preferably, said sensors are transducers, and are more preferably transducers which convert mechanical forces into electrical signals. For example, the sensors may detect strain, in which case resistive, optical, hall effect or capacitance-based transducers may be used; or deformation or deflection, in which case proximity, pressure differential, optical or capacitance-based transducers may be used.

The transducers may be physically connected to or in contact with the surface, e.g. in the case of resistive or variable reluctance transducers

where an arm of the transducer is connected to or biased into contact with the surface. Alternatively, there may be no physical contact between the sensors and the surface, e.g. in the case of capacitance, pressure or optical transducers.

The information data may relate to static or transient load centroid value, load orientation, contact shape, it may object recognition or dynamic information such as frequency, velocity or cadence. The system may comprise a display device for displaying the information data (which may require conversion to a user-readable form). Alternatively, or in addition, the output of the system may serve as an input for a logging system or an automated system for controlling a specific process.

Preferably, the processor incorporates an algorithm or other interpretation function, such as a neural network (e.g. a stochastic back-propagation trained network) which receives the sensory data and applies a non-linear transform to produce the information data. The processor may additionally or alternatively incorporate other non-linear transform components.

The deformable load bearing surface is preferably resiliently deformable and/or elastic. Suitable materials include rubber, plastics, metal and wood. The surface may be a laminate of two or more materials. The surface may be in the form of a flat sheet (planar) or alternatively moulded into a desired configuration. Deformation may be by a variety of mechanisms in response to shear, tensile and/or bending forces.

The deformable load bearing surface preferably forms part of a housing, the sensors preferably being sealed therein. Sealing the sensors within the housing avoids exposing the sensors to the external environment, thereby prolonging their operational lifespan and the physical robustness of the system to harsh environmental conditions.

In an alternative embodiment the housing contains a flowable material (e.g. liquid) which flows within or under the surface as part of the mechanism of the deformation response of the surface.. The sensors are arranged to detect pressure differentials due to the flow of material. The housing may also comprise one or more flow restrictors which affect the flow characteristics of the flowable material upon deformation of the surface. For example, the flowable material may be flowable within a porous material which partially or completely fills the housing. In a slight variation of the above preferred embodiment, the sensors are arranged to measure changes in distance between the surface and another part of the housing, e.g. its base.

For many applications the surface is conveniently flat. However, the system is not constrained to flat surfaces and the surface can be of any shape dependent upon its intended use.

The present invention also resides in a method of characterising a load applied to a load bearing surface comprising the steps of:-

(i) generating sensory data about the surface from a plurality of sensing elements operably coupled with the surface,

(ii) combining the sensory data into a single vector of inputs for a non-linear transformation,

(iii) applying a non-linear transformation to the vector of inputs whereby to generate information data characterising the load, and

(iv) outputting the information data, and

The output information may be, for example, information describing a contacting object, its state or its motion.

Steps (ii) and (iii) are preferably performed by a programmed computer. Hence the invention further resides in a carrier medium carrying a computer executable software program for controlling a computer to carry out steps (ii) and (iii) of the method of the present invention.

Preferably, the carrier medium is a storage medium, such as a floppy disk, CD-ROM, DVD or a computer hard drive. Although it will be understood that the carrier medium may also be a transient carrier e.g. an electrical or optical signal.

Embodiments of the invention will now be described by way of example only, with reference to the accompanying drawings in which:-

Figure 1 is a schematic representation of a generic system in accordance with the present invention,

Figure 2 is a schematic representation of a sensing system in accordance with the present invention,

Figure 3 shows the output from the system of Figure 2 under a load,

Figure 4 is a schematic representation of another sensing system in accordance with the present invention,
Figures 5 and 6 shows the output from the system of Figure 4 under different loads.

Referring to Figure 1, a generic system in accordance with the present invention comprises a surface 2 upon which a load 4 is applied, a plurality of sensors 6 coupled to the surface, a signal processor 8 to which the output from the sensors 6 is passed and an output display 10.

The system relies on the transmission of the response of the surface 2 to the contacting load 4 by the corresponding deformation of the surface continuum to strategically positioned sensor locations. The sensors 6 are used to detect local deformation or strain. By combining the sensor outputs as a simultaneous vector of inputs to the processor 8, a computer algorithm is used to determine descriptors that describe the load 4 as an output. The descriptors are those factors by which the load can be recognised by a user for output to the display 10, logging system or automated system for control of a process. The system can use both static and transient behaviour of the surface and sensing elements to describe the static and dynamic behaviour of the applied loads. The algorithm is usually a software function installed on a computer that is able to transpose the vector of inputs to the vector of descriptors of the output in 'Real Time'. For example, such functions can include fuzzy tools, neural networks and Karhunen Loève modal analysis.

An advantage of this sensing system is that there is strong coupling between the sensory data outputs, linked by the non-linear deformation behaviour of the surface. This means that relatively few sensory positions are needed to characterise the load (typically 4 to 5 on a flat surface), although additional sensory points can be used to increase redundancy in the system.

Example 1

Referring to figure 2, a sensing system in accordance with the invention comprises a load bearing element 20 having substantially planar upper 22 and lower sidewalls 24 which are mutually spaced by a short distance and a peripheral sidewall 26 which extends between the upper and lower sidewalls 22,24 around their periphery and is sealed therewith whereby to define an enclosed space 28 between the upper and lower sidewalls 22,24. The upper sidewall 22, which serves as the sensing surface in use, is made from an elastically deformable flexible material, in this case polythene, which is capable of deforming when subjected to a load 36. The lower side wall 24 serves as the base of the load bearing element 20 and for this embodiment is relatively rigid. The lower sidewall 24 is made from wood and the peripheral sidewall is an elastic sealing material.

The enclosed space 28 is filled with a compressible porous medium, in this case a sponge (not shown) and a flowable medium 30, in this case water. It will be understood that in other embodiments other flowable mediums may be employed (eg. oil, polymers or rubber compounds). In further embodiments, the sponge is replaced by a number of flexible tubes (optionally having flow restrictors therein) in which the flowable medium

30 is sealed. Also contained within the enclosed space 28 are three mutually spaced pressure transducers 32 which output a voltage according to changes in pressure at the transducer location. The transducers 32 are securely fixed in position between the upper and lower surfaces22,24. In alternative embodiments (not shown) other transducers are used, for example transducers whose output is dependent on the distance between the upper and lower sidewalls 22,24 at the transducer location. The transducers 32 are electrically connected to a computer with display 34 which is loaded with the necessary algorithms.

In use, when a load 36 is applied externally to the sensing surface 22 of the load bearing element 20, the sensor surface 22 deforms and locally compresses the porous medium within the enclosed space 28. In turn, this compression causes the liquid 30 within the enclosed space 28 to flow by a diffusion process. The pressure transients caused by the compression/liquid flow are measured at the transducers 32 and output as voltages varying with time. It will be understood that the pressure transients measured will be affected by the impedance to flow of the liquid 30, the elasticity/deformability of the sensing surface 22 and the nature and structure of the porous medium. In embodiments where the fluid medium is not 100% liquid, then the compliance of the fluid volume is also an influencing factor.

In one experiment, the system was configured to determine the position of the applied load 36 in one dimension. Pressure differentials were measured at the three transducer positions, with a typical set of transients being shown in figure 3. Using these simultaneous measurements it was

possible to work in the frequency domain to determine the amplitudes, phases and specific frequencies representing these transients using a Fast Fourier Transform (FFT) algorithm. These values were input into a trained neural network with a single output of position of the load. Using this simple approach, the measurement of position was to within 2% of the full range and was independent of load value.

Example 2

Referring to figure 4, the system is similar to that illustrated in figure 2. Four transducers 40 are employed and the load bearing element 42 is a flexible plastics sheet, but metal (eg. aluminium), wood and chipboard may also be used. The transducers 40 are strain gauges attached to the undersurface of the load bearing element 42, and they output a voltage dependent upon local bending forces applied to the load bearing element 42. The load bearing element 42 is mounted in a supporting frame 44.

A significant advantage of the systems of the present invention is that they allow three dimensional dynamic motion remote from the system to be analysed solely through the forces applied at the load bearing surface.

Determination of the efficacy of body motion in golf

In this application, the system of figure 4 was used to infer the kinetics and kinematics of a user practicing a golf swing from the reactive force transients under the feet. The system is able to determine the transients of pressure distribution beneath the feet through the response of the flexible load bearing sheet 42. The user stepped onto the flexible sheet 42 which deflects principally in bending. Upon swinging the golf club, the flexible

sheet 42 transmitted its response by transient deflections at the transducer sensing positions. A typical data set is shown in figure 5 for a golf driving swing. Based on the spatial-time data, estimates of the perturbations from the norm or ideal approach can be obtained by the evaluation of parameters that describe the deviation in the motion. Using a neural network, the perturbations from the ideal motion can be quantified in terms of the errors in the motion of the body. In this way, it is possible to identify flaws in the technique of the user and to automatically offer advice for improvement. A similar approach can be adopted for other types of activity, such as a racquet swing (a typical dataset for a badminton racquet swing being shown in figure 6), for gait information on a treadmill or dance technique on a dance floor.

For such multiple data time series for a single swing, it is possible to automatically partition the transient into distinct periods of the process and to evaluate the parameters describing the kinematics and kinetics of movement. For repetitive signals, such as in gait or repetitive racquet swings it is possible to apply other non-linear analysis such as Karhunen Loève modal analysis to evaluate non-linear model parameters relating the simultaneous sensory time-series data to the motion of the body directly.

The sensing systems of the present invention have a wide range of utility including but not limited to:-

- Determination of sport performance. The system can be incorporated into the belt of a treadmill for example, or as a mat where locomotion is not to be investigated.

- Determination of body performance in diagnostic and rehabilitation processes from gait or sway and balance.
- Recognition of foot conditions such as perturbations from the norm in pressure distribution caused by, for example, peripheral angiopathy (in diabetes)
- Security recognition systems to discriminate hand, foot and gait imprints.
- In leisure activities such as sport, monitoring and training systems such as in dance, karate, aerobics, gymnasium fitness equipment can be configured as a floor system.
- The same systems as for monitoring humans can be implemented to monitor animals for sport and health purposes.
- Livestock monitoring for position and the transients of gait.
- Traffic monitoring systems as an instrumented section of road, even some bridges. Load distribution in vehicles.
- Recognition of vehicle type, vehicle wheel loading, vehicle speed, density of traffic, state of suspension, tyre contact conditions, passenger type, operator recognition, operator consciousness. Control panels/surfaces.
- Redundant sensory key pad systems, keyboards, mouse pointing pads can be manufactured from non-electrical and non-metallic parts.
- In manufacturing processes, particularly in food and pharmaceutical processes the system is ideal for monitoring weight, position and size on static and moving surfaces.
- In healthcare applications:-

Surgery: flexible endoscopes, flexible laparoscopes, flexible tunnels for MIS, palpation information, remote navigation through tactile sensation.

Maintaining contact pressures between tools and devices, and tissues. At the micro/nano scale, measuring contact between devices and cells.

Medicine: Hand, size, shape, gesture and grip information, spinal shape. Performance in physiotherapy. Measurement and comparison of stance before and after surgery (Joint replacement), active implant and prosthetic devices operating from tactile feedback.

Figure 1

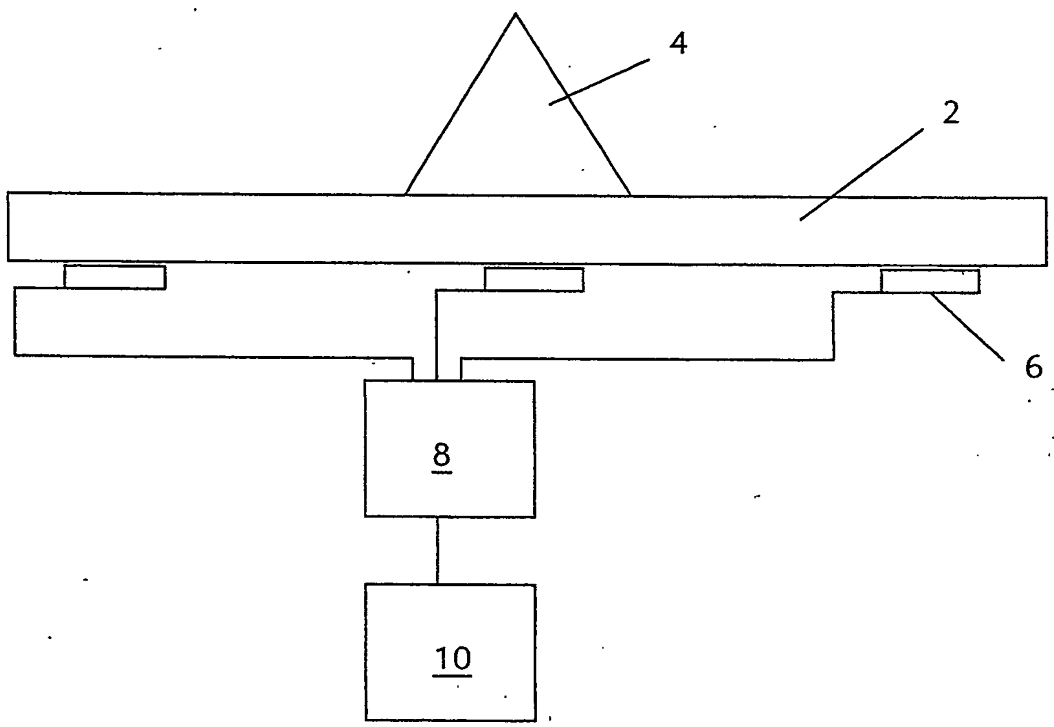


Figure 2

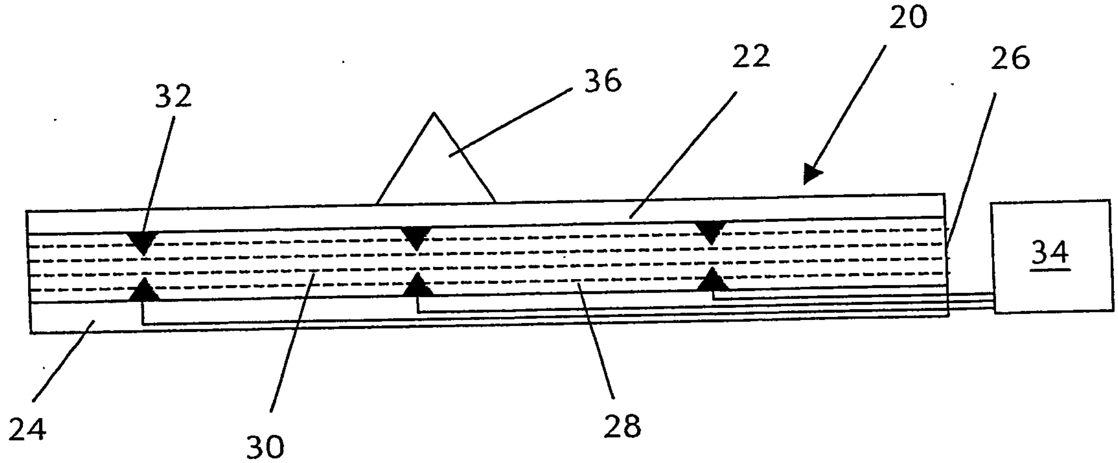


Figure 3

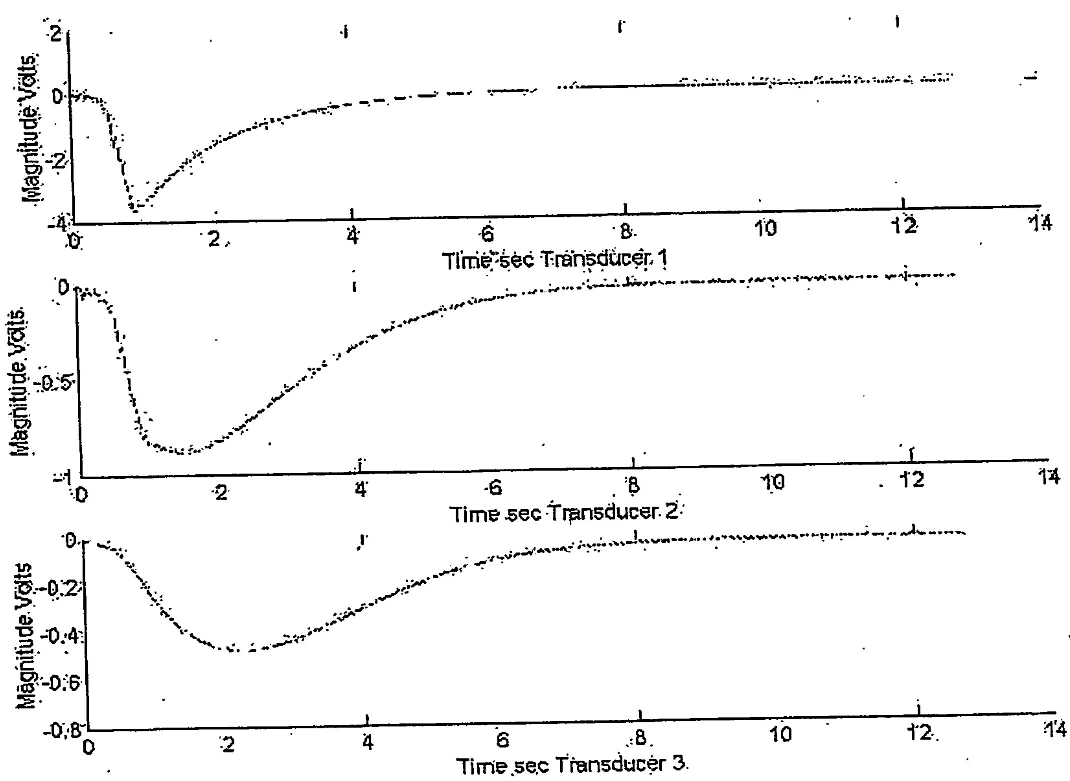


Figure 4

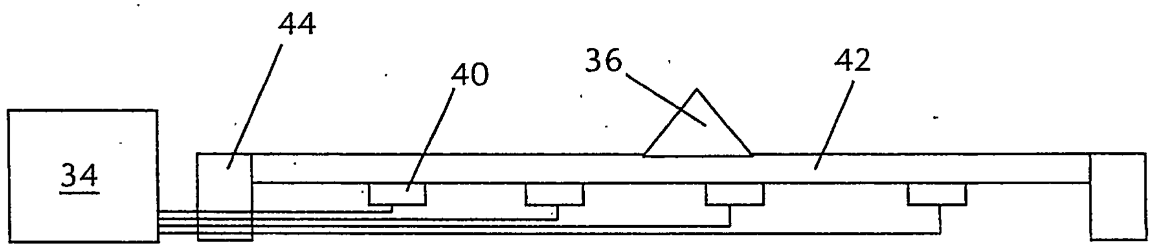


Figure 5

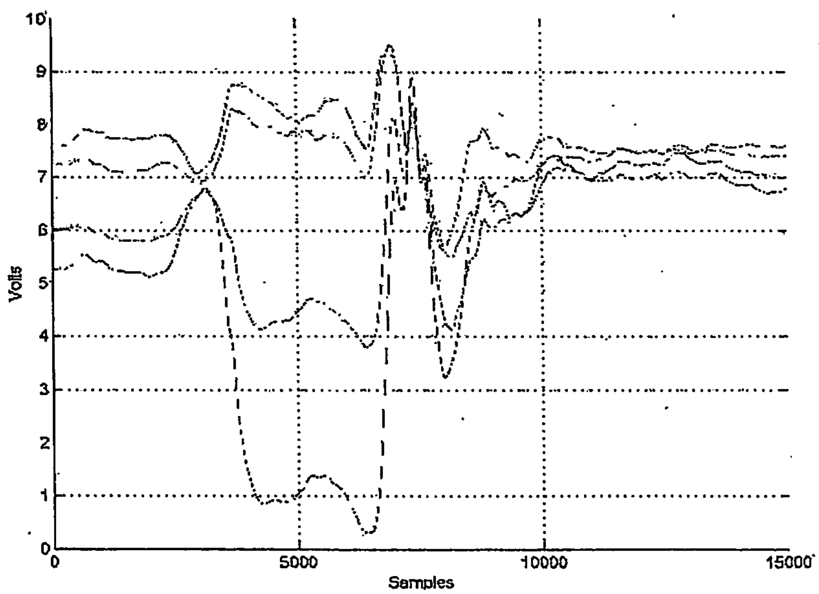
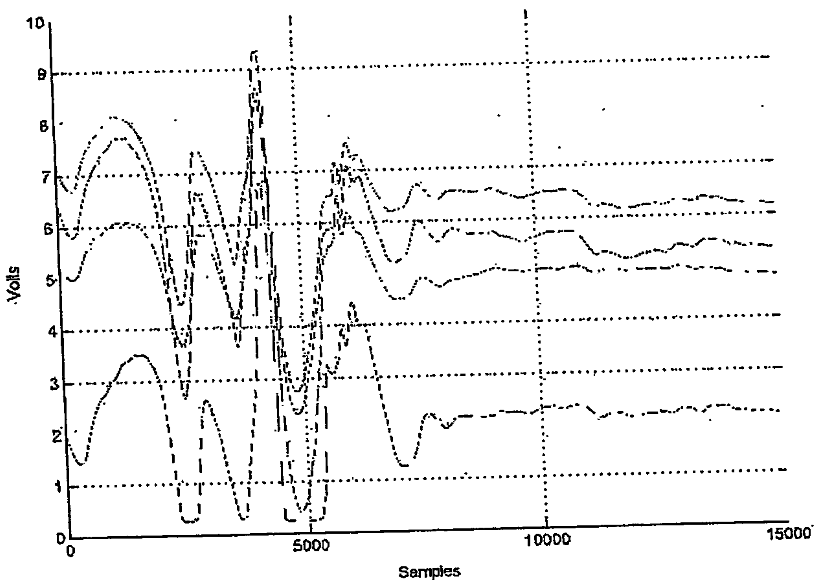


Figure 6



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